the eye, could we see it without absorption, these figures appear to show conclusively that it would be *blue*. Not to rely on any assumption, however, we have by various methods at Alleghany, reproduced this colour.

Thus (to indicate roughly the principle used), taking three Maxwell's discs, a red, green, and blue, so as to reproduce white, we note the three corresponding ordinates at the earth's surface spectrum, and comparing these with the same ordinates in the curve giving the energy at the solar surface; we re-arrange the discs, so as to give the proportion of red, green, and blue which would be seen *there*, and obtain by their revolution a tint which must approximately represent that at the photosphere, and which is most similar to that of a blue near Frauenhofer's "F."

The conclusion then is that while all radiations emanate from the solar surface, including red and infra-red, in greater degree than we receive them, that the blue end is so enormously greater in proportion, that the proper colour of the sun, as seen at the photosphere, is blue—not only "bluish," but positively and distinctly blue; a statement which I have not ventured to make from any conjecture, or on any less cause than on the sole ground of long continued experiments, which, commenced some seven years since, have within the past two years irresistibly tended to the present conclusion.

The mass of observations on which it rests must be reserved for more detailed publication elsewhere, at present I can only thank the Association for the courtesy which has given me the much prized opportunity of laying before them this indication of methods and results.

UNDERGROUND TEMPERATURE[1]

II.

E. We now proceed to a Comparison of Results.

THE localities at which definite results have been obtained may thus be classified:—

1. Metallic mines. 2. Coal mines. 3. Wells and wet borings. 4. Tunnels.

1. The mines at Przibram in Bohemia, with a depth of 1900 feet, are in very quartzose rock, and give a very slow rate of increase, viz. 1° F in 135 feet. As all the shafts are in lofty hills, an allowance of $\frac{1}{15}$ may be made for convexity, leaving 1° F. in 126 feet. Quartz is found by Prof. Herschel to have a conductivity of about ·0086.

The mines at Schemnitz in Hungary, with a depth of 1368 feet, give an average rate of 1° F. in 74 feet, the rock being a green hornblende-andesite (in German, *Grünstein-Trachyt*), which is a compact, fine-grained, crystalline, more or less vitreous rock. Prof. Lebour estimates its conductivity as being probably nearly the same as that of Calton Hill trap-rock, which Prof. Herschel found to be about ·0029.

2. The principal results from coal mines are as follows:—

The mines of the Société Cocqueril at Seraing (Belgium), with a depth of 1657 feet, give an average rate of 1° F. in 50 feet. The rock is coal shale. Prof. Herschel found for shale the low conductivity ·0019.

The mines of Anzin, in the north of France, with a depth of 658 feet, gave in the deepest shaft an increase of 1° in 47 feet.

Rosebridge Colliery, near Wigan, with a depth of 2445 feet, gave a mean rate of 1° in 54 feet.

The four following are in the East Manchester coalfield:—

Astley Pit, Dukinfield, with a depth of 2700 feet, gave a mean rate of 1° in 72 feet.

Ashton Moss Colliery, with a depth of 2790 feet, gave 1° in 77 feet.

Bredbury Colliery, with a depth of 1020 feet, gave 1° in 78·5 feet.

Nook Pit, with a depth of 1050 feet, gave 1° in 79 feet.

South Hetton Colliery, Durham, with a depth of 1929 feet, including a bore hole at bottom, gives very consistent observations at various depths, and an average rate of 1° in 57·5 feet.

Boldon Colliery, between Newcastle and Sunderland, with a depth of 1514 feet, and excellent conditions of observation, gives an average rate of 1° in 49 feet.

Kingswood Colliery, near Bristol, with a depth of 1769 feet, and remarkable consistency between observations at various points, gives 1° in 68 feet.

Prof. Phillips' observations in Monkwearmouth Colliery, published in *Phil. Mag.* for December 1834, showed a temperature of 71·2 in a hole bored in the floor of a recently exposed part at the depth of 1584 feet. The surface of the ground is 87 feet above high water, and the mean temperature of the air is assumed by Prof. Phillips to be 47·6. If, as usual, we add 1° to get the soil temperature, instead of assuming, as Prof. Phillips does, that the temperature 100 feet deep is identical with the air temperature at the surface, we obtain a rate of increase of 1° in 70 feet.

3. The following are the most trustworthy results from wells and borings:—

The Sperenberg bore, near Berlin, in rock salt, with a depth of 3492 English feet, to the deepest reliable observation, gave an average of 1° in 51·5 feet. This result is entitled to special weight, not only on account of the great depth, but also on account of the powerful means employed to exclude convection.

Rock salt, according to Prof. Herschel, has the very high conductivity ·0113.

Three artesian well in the chalk of the Paris Basin gave the following results:—

	Feet.		Rate. Feet.
St. Andre, depth of observation ...	830	...	1 in 56·4
Grenelle	1312	...	1 in 56·9
Military School	568	...	1 in 56·2

An artesian well at St. Petersburg, in the Lower Silurian strata, with a depth of 656 feet, gave about 1° in 44 feet.

A well sunk at Yakoutsk, in Siberia, to the depth of 540 feet, disclosed the fact that the ground was permanently frozen to this depth, and probably to the depth of 700 feet. The rate of increase of temperature was 1° in 52 feet.

Of the English wells in which observations have been taken, the most important is that at Kentish Town, in which Mr. G. J. Symons, F.R.S., has taken observations to the depth of 1100 feet. The temperatures at different depths form a smooth series, and have been confirmed by observations repeated at long intervals. The only question that can arise as to the accuracy of the results is the possibility of their being affected by convection.

The well is 8 feet in diameter, with brickwork to the depth of 540 feet, and this part of it is traversed by an iron tube 8 inches in diameter, which is continued to the depth of more than 1300 feet from the surface. The tube is choked with mud to the depth of about 1080 feet, so that the deepest observations were taken under 20 feet of mud. The temperature at 1100 feet was 69°·9, and by combining this with the surface temperature of 49°·9 observed at the Botanic Gardens, Regent's Park, we obtain a rate of 1° in 55 feet. These data would give at 250 feet a calculated temperature of 54·5, whereas the temperature actually observed at this depth was 56·1, or 1°6 higher; the temperature at 300 feet and at 350 feet being also 56·1. This seems to indicate convection, but it can be accounted for by convection in the 8-foot well which surrounds the tube, and does not imply convection currents within the tube. Convection currents are much more easily formed in water columns of large diameter than in small ones, and the 20 feet of mud at the bottom give some security against convection at the deepest point of observation. It is important to remark that the increase from 1050 to 1100 feet is rather less than the average instead of being decidedly greater, as it would be if there were convection above, but not in, the mud. The rate of 1° in 55 feet may therefore be adopted as correct.

The strata consist of tertiary strata, chalk (586 feet thick), upper greensand, and gault.

The Kentish Town temperature at the depth of 400 feet (58°) is confirmed by observations in Mr. Sich's well at Chiswick, which is 395 feet deep, and has a temperature varying from 58° to 57°·5.

The Bootle well, belonging to the Liverpool Waterworks, is 1302 feet deep, and the observations were taken in it during the sinking. The diameter of the bore is 24 inches, and convection might have been suspected but for the circumstance that there was a gradual upward flow of water from the bottom, which escaped from the upper part of the well by percolation to an underground reservoir near at hand. This would check the tendency to downflow of colder water from the top; and as the observations of temperature were always made at the bottom, they would thus be protected against convective disturbance.

The temperature at 226 feet was 52°, at 750 feet 56°, at 1302 feet 59°, giving by comparison of the first and last of these a mean rate of 1° in 154 feet. The circumstance that the boring

[1] Continued from p. 567.

ceased for six weeks at the depth of 1004 feet, and the temperature fell during this interval from 58°·1 to 57°·0, would seem to indicate an elevation of 1° due to the heat generated by the boring tool. An assumed surface temperature of 49° (only 0°·9 lower than that of the Botanic Gardens in London) would give by comparison with 57°, at 1004 feet, a rate of 1° in $125\frac{1}{2}$ feet, and by comparison with 59°, at 1302 feet, a rate of 1° in 130 feet, which last may be adopted as the best determination. The rock consists of the pebble beds of the Bunter or Lower Trias, and the boring was executed at the rate of nearly 100 feet per month.

The boring at Swinderby, near Scarle (Lincoln), in search of coal, was carried to a depth of 2000 feet, with a diameter at the lower part of only $3\frac{1}{8}$ inches—a circumstance favourable to accuracy, both as impeding convection and as promoting the rapid escape of the heat of boring. The temperature at the bottom was 79°, the water having been undisturbed for a month, and this by comparison with an assumed surface temperature of 50° gives a rate of 1° in 69 feet.

The rocks are Lower Lias, New Red Marl (569 feet thick), New Red Sandstone (790 feet thick), Red Marl, and earthy Limestone.

The following results have been obtained from shallow borings. The first three were made under Sir William Thomson's direction, with a thermometer which could be read by estimation to hundredths of a degree:—

Blythswood bore, near Glasgow, with a depth of 347 feet, gave a very regular increase of 1° in 50 feet.

Kirkland Neuk bore, in the immediate vicinity of the above, gave consistent observations at different seasons of the year from 180 feet to the bottom (354 feet), the rate being 1° in 53 feet. This bore passed through coal which had been "very much burned or charred."

South Balgray bore, near Glasgow, and north of the Clyde, with an available depth of 525 feet, gave by comparing the temperature at the bottom with that at 60 feet a rate of 1° in 41 feet.

Shale extends continuously from 390 to 450 feet from the surface, and the increase in these 60 feet of shale was 2°·02, which is at the rate of 1° in 30 feet. This rapid increase agrees with the fact that shale has very low conductivity, averaging ·0019 in Prof. Herschel's experiments.

The only small bore remaining to be mentioned is that at Manegaon, in India, which had 310 feet available, and gave by comparing the temperature at this depth with that at 60 feet a rate of 1° in 68 feet. The rocks consist of fine softish sandstones and hard silty clays, the dip being 10°.

4. *Tunnels.*—The Mont Cenis tunnel, which is about seven miles long, is at a depth of exactly a mile (5280 feet) beneath the crest of Mont Fréjus overhead. This was the warmest part of the tunnel, and had a temperature of 85°·1 F. The mean air temperature at the crest overhead was calculated by the engineer of the tunnel, M. Giordano, by interpolating between the known temperature of the hill of San Theodule and that of the city of Turin, the former being 430 metres higher, and the latter 2650 metres lower, than the point in question. It is thus calculated to be − 2°·6 C. or 27°·3 F. If, according to our usual rule, we assume the ground to be 1° warmer than the air, we have 28°·3 to compare with 85°·1. This gives a rate of 1° in 93 feet; but, inasmuch as the convexity of the surface increases the distance between the isotherms, a correction will be necessary before we can fairly compare this result with rates under level ground. As a rough estimate we may take $\frac{7}{8}$ of 93, and adopt 1° in 79 feet, as the corrected result.

"The rocks on which the observations have been made are absolutely the same, geologically and otherwise, from the entrance to the tunnel, on the Italian side, for a distance of nearly 10,000 yards. They are not faulted to any extent, though highly inclined, contorted, and subjected to slight slips and slides. They consist, to a very large extent indeed, of silicates, chiefly of alumina, and the small quantity of lime they contain is a crystalline carbonate."

The St. Gothard Tunnel, which has a length of about nine miles, has been subjected to much more minute observation, a skilled geologist, Dr. Stapff, having, under Government direction, devoted his whole time to investigating its geology and physics. He not only observed the temperature of the rock in the tunnel at very numerous points, but also determined, by observations of springs, the mean temperatures of the surface of the mountain at various points, and compared these with an empirical formula for air temperature deduced from the known mean temperatures of the air at Göschenen, Andermatt, Airolo, and the Hospice of St. Bernard. He infers from his comparisons a considerable excess of soil above air temperature, increasing from 2° C. at the ends of the tunnel to 6° C. at the crest of the mountain over the centre of the tunnel. The highest temperature of the rocks in the tunnel was at this central part, and was about 30°·6 C. or 87° F. The soil temperature at the crest above it was about − 0°·6 C., or 31° F., giving a difference of 56° F. The height of the crest above sea-level was about 2850 m., and that of the tunnel at this part 1150 m., giving a difference of 1700 m. or 5578 feet. The rate of increase here is, therefore, about 1° F. in 100 feet; and if we apply the same correction for convexity as in the case of the Mont Cenis Tunnel, this will be reduced to about 1° F. in 87 feet, as the equivalen rate under a level surface. From combining his observations in all parts of the tunnel through the medium of empirical formulæ, Dr. Stapff deduces an average rate of 1° F. for every 88 feet measured from the surface directly overhead. Where the surface is a steep ridge, the increase was less rapid than this average; where the surface was a valley or plain, the increase was more rapid. As this average merely applies to the actual temperatures, the application of a correction for the general convexity of the surface would give a more rapid rate. If we bring the isotherms nearer by one part in 15, which seems a fair assumption, we shall obtain a rate of 1° F. in 82 feet.

Collecting together all the results which appear reliable, and arranging them mainly in the order of their rates of increase, but also with some reference to locality, we have the following list:—

	Depth feet	Feet for 1° F
Bootle waterworks (Liverpool	1392	130
Przibram mines (Bohemia)	1900	126
St. Gothard tunnel	5578	82
Mont Cenis tunnel	5280	79
Talargoch lead mine (Flint)	1041	80
Nook Pit, Colliery (East Manchester coalfield)	1050	79
Bredbury ,, (East Manchester coalfield)	1020	$78\frac{1}{2}$
Ashton Moss ,, (East Manchester coalfield)	2790	77
Denton ,, (East Manchester coalfield)	1317	77
Astley Pit, Dukinfield (East Manchester coalfield)	2700	72
Schemnitz mines (Hungary)	1368	74
Scarle boring (Lincoln)	2000	69
Manegaon boring (India)	310	68
Pontypridd colliery (S. Wales)	855	76
Kingswood colliery (Bristol)	1769	68
Radstock ,, (Bath)	620	62
Paris artesian well, Grenelle	1312	57
,, ,, St. André	830	56
,, ,, Military School	568	56
London ,, Kentish Town	1100	55
Rosebridge colliery (Wigan)	2445	54
Yakoutsk, frozen ground (Siberia)	540	52
Sperenberg, boring in salt (Berlin)	3492	$51\frac{1}{2}$
Seraing collieries (Belgium)	1657	50
Monkwearmouth collieries (Durham)	1584	70
South Hetton ,, ,,	1929	$57\frac{1}{2}$
Boldon ,, ,,	1514	49
Whitehaven ,, (Cumberland)	1250	45
Kirkland Neuk bore (Glasgow)	354	53
Blythswood ,, ,,	347	50
South Balgray ,, ,,	525	41
Anzin collieries (North of France)	658	47
St. Petersburg, well (Russia)	656	44
Carrickfergus, shaft of salt mine (Ireland)	770	43
,, ,, ,,	570	40
Slitt mine, Weardale (Northumberland)	660	34

The depth stated is in each case that of the deepest observation that has been utilised.

F. In deducing a Mean from these very Various Results, it is better to operate not upon the number of feet per degree, but upon its reciprocal—the increase of temperature per foot. Assigning to the results in the foregoing list weights proportional to the depths, the mean increase of temperature per foot is found to be ·01563, or about $\frac{1}{64}$ of a degree per foot—that is, 1° F. in 64 feet.

It would be more just to assign greater weight to those single results which represent a large district or an extensive group of

mines, especially where the data are known to be very accurate. Doubling the weights above assigned to Przibram, St. Gothard, Mont Cenis, Schemnitz, Kentish Town, Rosebridge, and Seraing, and quadrupling that assigned to Sperenberg, no material difference is made in the result. The mean still comes out 1° F. in 64 feet, or more exactly ·01566 of a degree per foot.

This is a slower rate than has been generally assumed, but it has been fairly deduced from the evidence contained in the Committee's Reports; and there is no reason to throw doubt on the results in the upper portion of the above list more than on those in its lower portion. Any error that can reasonably be attributed to the data used in the calculations for the St. Gothard Tunnel and for the numerous deep mines of the East Manchester coalfield, will have only a trifiing effect on the rates of increase assigned to these localities.

To obtain an approximation to the rate at which heat escapes annually from the earth, we will first reduce the above rate of increase ·01566 to Centigrade degrees per centimetre of depth. For this purpose we must multiply by ·0182, giving ·000285.

To calculate the rate of escape of heat, this must be multiplied by the conductivity.

The most certain determinations yet made of the conductivity of a portion of the earth's substance are those deduced by Sir William Thomson by an indirect method, involving observations of underground thermometers at three stations at Edinburgh, combined with laboratory measurement of the specific heats and densities of the rocks in which the thermometers were planted. The specific heats were determined by Regnault, and the densities by Forbes. Specific heats and densities can be determined wiih great accuracy in the laboratory, but the direct determination of conductivity in the laboratory is exceedingly difficult, it being almost impossible to avoid sources of error which make the conductivity appear less than it really is.

Prof. Herschel, in conjunction with a Committee of the British Association, has made a very extensive and valuable series of direct measurements of the conductivities of a great variety of rocks, and has given additional certainty to his results by selecting as two of the subjects of his experiments the Calton Hill Trap and Craigleith sandstone, to which Sir William Thomson's determinations apply.

From combining Prof. Herschel's determinations with those of Sir Wm. Thomson, ·0058 is adopted as the mean conductivity of the outer crust of the earth, which, being multiplied by the mean rate of increase, ·000285, gives

$$16330 \times 10^{-10}$$

as the flow of heat in a second across a square centimetre. Multiplying by the number of seconds in a year, which is approximately $31\frac{1}{2}$ millions, we have

$$1633 \times 315 \times 10^{-4} = 41{\cdot}4.$$

This, then, is our estimate of the average number of gramme-degrees of heat that escape annually through each square centimetre of a horizontal section of the earth's substance.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE

CAMBRIDGE.—The lists of Boards of Studies for the first time include the separate Boards of Physics and Chemistry, and of Biology and Geology, as constituted by the new Statutes. The Woodwardian Professor appears in both Boards. The Physiology Professor, not being yet appointed, only appears in brackets; the same is the case with the Professor of Pathology in the Board of Medical Studies.

The new Statute B having been finally approved, determines that in 1883 and 1884, a sum of between 5000*l.* and 6000*l.* in each year will become available for University purposes from College revenues, subject only to deduction of 40*l.* by each College for each Professorial Fellowship held at the College.

The Professors of Physiology, Pathology, and Mental Philosophy and Logic are to be appointed in such order as the University may think fit, as soon as sufficient funds can be provided conveniently for the purpose from the common University fund, or from other sources. The Professors of Physiology and of Pathology are not to undertake the private practice of medicine or surgery. The stipends are fixed at 800*l.* for these two Professors, and 700*l.* for the Professor of Mental Philosophy.

The appointment of Readers is similarly dependent on the convenient provision of funds. Thus, until the Council of the Senate has published its recommendations, nothing certain can be said as to the objects upon which it will be thought wisest first to expend the new funds accruing. But it must not be forgotten that a considerable amount of the new income will be required to pay the increased stipends of present professors.

Prof. Liveing will lecture on the General Principles of Chemistry this term, and also take practical classes in spectroscopic analysis. Prof. Dewar will lecture on Physical Chemitry, and Tutorial lectures will be given in connection with this course by Mr. A. Scott, Prof. Dewar's assistant. Demonstrations in volumetric chemistry will be given by one of the demonstrators.

Lord Rayleigh will lecture on Electrical Measurements to advanced students; Mr. Glazebrook will give demonstrations on Electricity and Magnetism, and Mr. Shaw on Heat in the Cavendish Laboratory. Mr. Trotter will give an elementary course on Electricity and Magnetism at Trinity College, and also a course on Optics and Light.

Mr. Vines will lecture on the Physiology of Plants, at Christ's College, in connection with practical work, and will also give an elementary course at the New Museums, especially for medical students. The Assistant Curator of the Herbarium, Mr. T. H. Corry, B.A., of Caius College, will give a series of demonstrations on the natural orders of plants.

Prof. Stuart will lecture on Mechanism and Applied Mechanics, and the workshops and drawing office will be opened to pupils on October 13. At Gonville and Caius College one or more Entrance Scholarships of values varying from 40*l.* to 80*l.* according to merit of candidates, will be awarded in Natural Science by an examination beginning on January 8 next. They are only open to candidates under nineteen years of age on the first day of examination, and are tenable only for one year, after which a foundation scholarship may be awarded. The subjects are Physics, Chemistry, Biology, and Animal Physiology; two subjects at least are required, Chemistry being essential. Particulars of subjects may be learnt on applicaiion to the Senior Tutor, Rev. A. W. Steel. Scholarships may also be awarded for Mathematics and Natural Science combined.

The examination for Entrance Scholarships at Emmanuel College will commence on January 12. They are tenable in the first instance for two years. The subjects in Natural Science are Chemistry, Physics (including Dynamics and Hydrostatics), Elementary Biology, and Geology and Mineratogy. Candidates may also obtain scholarships for Mathematics and Natural Science combined. Mr. W. Chawner, the tutor, will supply all information.

Mr. A. Sedgwick, of Trinity College, Cambridge, will conduct the classes in Morphology which Prof. Balfour had announced for the present term.

SCIENTIFIC SERIALS

The Journal of Anatomy and Physiology (*Normal and Pathological*), vol. xvi. pt. iv., July, 1882, contains:—Observations in comparative myology, by Dr. Hans Gadow. The first section of this interesting paper is devoted to the important subject of a scientific nomenclature for muscles.—On fat embolism, by Drs. R. Saundby and G. Barling (with a plate).—On Micrococcus poisoning, by Dr. Alex. Ogston.—On the action of saline cathartics, by Dr. M. Hay (D and E series of experiments).—On a variety of pulmonary lobation and its relation to the thoracic parietes, as illustrated by comparative anatomy and abnomalities in the human subject, by Dr. W. Allen.—Prof. Gegenbaur, critical remarks on polydactyly as atavism; translated by Drs. Garson and Gadow.

The American Naturalist for August, 1882, contains—On the compass plant, by B. Alvord.—On the development of the tree toad, by M. H. Hinckley.—On some entomostraca of Lake Michigan and adjacent waters, by S. A. Forbes.—Organic physics, by Charles Morris.—The Editor's table.—Recent lite-

The same for September, 1882, contains—The methods of microscopical research adopted in the Zoological Station in Naples, by C. O. Whitman.—Notes on the habits of the "Savannah cricket frog," by C. C. Abbott.—On the evolution of forms from the Clinton to the Niagara group, by E. N. S. Ringueberg.—On hypnotism in animals, by Dr. W. Prentiss.

The Transactions and Proceedings of the New Zealand Institute for 1882, being vol. xiv., edited by Dr. J. Hector, F.R.S., and published at Wellington, May, 1882, have just reached us. They form a royal octavo volume of over 600 pages and 39 plates.